ENHANCED LETHALITY MULTI-PURPOSE TANK MUNITION FOR FCS

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ABSTRACT

Responding to the materiel needs of the U.S. soldier is a challenge requiring engineers and scientists to bridge capability gaps by developing systems that counter or prevent the threats of our enemies. The Armament Research, Development, and Engineering Center (ARDEC) continually reacts to these needs by developing and inserting advancing technology to create systems which effectively allow our soldiers to dominate the battlefield. Along the front line, infantry and mounted task forces provide street level defense and security, subsequently creating a need for munitions in urban combat. These needs translate into user requirements which are generally designated as specifications for a munition, and ultimately define key goals for a project.

Specifically within ARDEC, the Mounted Combat System (MCS) and Abrams Ammunition System Technologies Army Technology Objective (MAAST-ATO) aims to develop and enhance large caliber ammunition and related systems. Within this area of development, ARDEC in 2 years subsequently demonstrated a single multi-purpose munition that can effectively defeat various urban targets. This munition is known as 120mm XM1069 Line-of-Sight Multi-Purpose munition (LOS-MP).

The LOS-MP was created by Government engineers and scientists by merging new technology in the areas of warheads, fuzing and system integration into a new munition that has met technology readiness level (TRL) 6 exit criteria. Development of the XM1069 required the system engineering process be accelerated to meet the program's two year time table. In the past, this would have seriously limited the progress that could have been made within the time constraints. Extensive use of modeling and simulation (M&S) provided engineers and scientists the ability to design and analyze system and subsystem components while reducing the program schedule and cost by lessening the burden of physically testing the system. For the LOS-MP, a variety of M&S analyses yielded expected levels of warhead performance against defined targets in terms of lethality, as well as structural integrity and ballistic metrics. This data permitted design decisions to be made early and with confidence, reducing risk and accelerating development.

1. INTRODUCTION

The 120mm XM1069 LOS-MP is a multi-purpose, high explosive tank munition capable of defeating hardened targets and enemy personnel through the employment of a multi-mode programmable base-detonating fuze and blast fragmenting target penetrating warhead. The fuze, the XM1157, also designed by ARDEC, provides five modes for maximized target effectiveness. Four point detonate modes for hard target engagements and one programmable airburst mode for anti-personnel engagements can be selected. On detonation, the warhead provides several times the lethal area of the M830 against enemy personnel as well as the ability to defeat double-reinforced concrete walls, earth

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and timber bunkers, and light armor targets (*See **Table 1.1** for Exit Criteria)*. This system effectively combines the abilities of existing stockpile ammunition, including the 105mm M393A3 and 120mm M830, M830A1, M908, and M1028 tank cartridges.

Table 1.1. 120mm XM1069 LOS-MP MAAST-ATO Exit Criteria

Capability	Baseline	Threshold	Objective
Double-Reinforced Concrete Wall	120mm M830, M830A1, M908 105mm M393A3	30"x50" Unobstructed Hole in 3 Shots	30"x50" Unobstructed Hole in 1 Shot
Anti-Personnel	120mm M1028 Canister	200 – 700 Meters	40 – 2000 Meters

The development of the LOS-MP was sponsored by ASA(ALT) as part of the MAAST-ATO. The effort resulted in the demonstration of a TRL 6 system that created a transitional baseline for SDD that will significantly reduce development time, cost, and risk associated with the procurement of new materiel solutions for the soldier. In addition, the development process further proved the value of modeling and simulation for munitions, showing good design decisions could be made in limited time and that system performance, in a relevant environment, could be predicted accurately.

2. SCIENCE & TECHNOLOGY

The translation of user requirements into a functional design was performed by IPT members from various backgrounds. Their specialization in the areas of S&T shaped the design of the system so the user's needs would be met in one munition according to appropriate methods and standards. Several new and advanced technologies were chosen to be incorporated into the LOS-MP, including PAX-3 high blast explosive, bash through warhead design, XM859 boom and fin system, pre-fragmented nose cone, and fuze data link. These components were modeled and then simulated iteratively throughout the systems engineering process. Component selection was based on M&S results as well as cost to benefit analysis.

Foremost, PAX-3 explosive was chosen due to its high chemical energy, insensitive characteristics, and one-stage pressing into a warhead body. PAX-3 (Picatinny Arsenal Explosive) high blast explosive is a well balanced explosive. PAX-3 offers significant blast properties making it very capable against Military Operations in Urban Terrain (MOUT) targets yet still provides good performance for driving metal fragments to lethal velocities.

Incorporation of the pre-fragmented nose cone was essential to the effectiveness of the LOS-MP for anti-personnel. When used on the ARDEC developed 40mm ALACV airburst munition, the pre-fragmented nose displayed a high level of effectiveness to penetrate targets through the use of dense fragments embedded in an easily fractured matrix. Additionally, a designated shape that projects fragments in a conical pattern provides additional lethal area not provided by the warhead body itself. The primary architecture had to be modified, however, to ensure survival for target penetration. Without the use of this component in the design, the LOS-MP would be significantly less lethal against anti-personnel targets.

The LOS-MP was designed as a full-bore projectile to maximize the amount of energy and fragments put on target. As a full-bore design, lessons learned showed that super-caliber fins improved the flight performance of full-bore projectiles where sub-caliber fins did not. Use of a proven folding-fin system on a rigid boom demonstrated excellent flight stability and static margin of 18%.

Advanced capabilities desired in a 120mm package required a step forward in electronics technology. Technological progress is occurring in the ability to send and receive power or data to a projectile. The Data Link primer served as a stepping stone in the powering of the fuze, while the development of a sister technology, the data link case base, is ongoing and currently being tested. As the future for programmable tank munitions, the data link case base is being designed to serve the MCS and upgraded Abrams tanks enabled with a data link breech. This will allow the transfer of commands from the fire control system to be programmed into future munitions, allowing advanced targeting and other features.

As no current tank fuze has the capabilities required to perform the functions necessary to control varying responses of the fuze, ARDEC designed, developed, and prototyped a multi-mode programmable, electronic fuze that is microprocessor controlled and is powered during gun launch, but prior to ignition. The XM1157 fuze is the first newly U.S. developed tank fuze in twenty years, and is dual-safe via the set-back safety within the safe and arm device and the electronic firing of a secondary rotor stop upon a commitment to launch, or firing of the gun. While the XM1157 fuze provides precise timing for detonation in all modes, science and theory of how to best defeat the required target sets drove the selection of what timing should be used for specific targets. The difficulty of rebar removal from double-reinforced concrete walls, for instance, had shown to be manageable

by embedding the warhead within the target as much as possible rather than detonate on the fore or aft surface. The past performance of fielded ammunition, as well as relevant testing of the LOS-MP had shown this through analysis of target hole size. Proper embedding of the projectile provided optimal rebar removal by allowing the mechanical energy produced by detonation to push the rebar outward and evenly from the impact point. Otherwise improper embedding of the projectile provided mixed results where more concrete may have been removed; yet significant rebar remained, increasing the difficulty of, or completely preventing traversal.

Additional development was also done in terms of the projectile. The airframe had to be designed and developed to enable the LOS-MP to meet its defined requirements. The airframe utilized creative design approaches in integration and material mechanics to optimize fragmentation, while maintaining structural integrity to penetrate hardened targets. As a result of the concept's generation, the LOS-MP design employed ARDEC patented components, while ten new patent pending designs have been filed for previously mentioned items.

3. MODELING AND SIMULATION

Modeling and simulation of the LOS-MP and its components not only reduced the amount of time that was required to develop the system, but was also estimated to save over 54% of the total program budget in hardware, labor, and range testing costs. While remarkable, it was even more impressive how accurately that M&S predicted the LOS-MP's structural integrity and lethality for its valued target sets. The process of modeling and then simulating the performance of the LOS-MP was detailed and iterative; initiating and then regenerating component and assembly models based upon the performance values that were output by the various M&S packages that were used. ***Figure 3.1*** details this, in addition to the inputs and outputs by package and how it fed the design process.

Modeling each component of the projectile assembly was the first step in the LOS-MP design process, individually reflecting certain aspects and features recommended by IPT members as well as the interface standards needed for a 120mm system. Key load bearing parts were then analyzed using ANSYS and Pro Mechanica to ensure structural integrity during gun launch and flight. Subsequently, each step in the modeling and simulation process was completed and indicated relative performance, moving the modeling and simulation process forward or initiating redesign to better meet desired values. This process was followed through the confirmation of optimized ballistic performance and structural integrity. At that point, parts were manufactured and a thorough lethality model was created against anti-personnel and armored targets. ***Table 3.1*** details the M&S path as well as the inputs and outputs to the model.

PRODAS was used to analyze the projectile assembly for ballistic performance. Ensuring flight stability, limiting drag, and optimization of yaw cycle were the most important factors in determining how well the projectile would perform out of the gun. After a robust and reliable design was confirmed, simulations were performed using CALE and the ARDEC-developed PA FRAG program, providing the resulting fragment size, quantity, velocity, and direction induced by detonation of the loaded explosive. This data was compiled into a Joint Munitions Effectiveness Model (JMEM) and imported by CASRED for anti-personnel lethality analysis. This analysis was executed using the baseline target set data of the M1028 canister cartridge, which consists of a thirty-man platoon arranged in three ten-man V-shaped squads. Unfortunately, since this model assumed optimal projectile ballistics and system function, the output data from CASRED was imported into the ARL-developed MPD3D program, which provided anti-personnel lethality data corrected for ballistic and system errors. Additional performance analysis was done using the MUVES lethality model, using the same inputs as CASRED to calculate incapacitation values against armored targets.

Modeling and simulation was also performed during the creation of the XM1157 fuze components. Since the fuze is electronically controlled, circuit design and software programming was necessary to ensure desired function. Altium Pro was used to create the circuit layout and aided in the proper optimization of schematics for the manufacture of fuze electronics. Proprietary coding software for the XM1157 microprocessor also permitted simulated function of the fuze, including the release of the secondary S&A rotor lock and detonator firing time. This essentially verified how the electronics would function, provided that there was no failure powering the fuze via Data Link prior to ignition.

In essence, modeling and simulation accelerated the decision making process involved in engineering the LOS-MP by ensuring that the projectile would perform well ballistically and be able to structurally withstand

Table 3.1. Modeling and Simulation path with its inputs and outputs.

Sequence	Package(s)	Inputs	Outputs
1	Pro/Engineer	Design intent, interface standards, IPT member recommendations	Design geometry, material properties
2	ANSYS, Pro Mechanica	Design geometry, material properties, supports, static loads	Structural response
3	PRODAS	Design geometry, material properties, gun pressure	Flight stability, drag profile, yaw cycle, trajectory, muzzle velocity, static margin, deceleration, muzzle jump factor
4	PA Frag	Design geometry, material properties, explosive properties	Size & quantity of fragments induced by detonation
	CALE	Design geometry, material properties, explosive properties	Fragment velocity & direction induced by detonation
5	CTH	Design geometry, material properties, supports, dynamic loads	Structural integrity against double-reinforced concrete wall
System components were manufactured and relevant testing commenced			
6	CASRED	JMEM file; Fragment size, quantity, velocity, & direction; Projectile ballistics	Anti-personnel lethality; Probability of incapacitation
	MUVES	Fragment size, quantity, velocity, & direction; Projectile ballistics	Armored vehicle lethality; Probability of immobilization & kill
7	MPD3D	Anti-personnel lethality; Probability of incapacitation; Ballistic and system errors	Corrected anti-personnel lethality; Probability of incapacitation

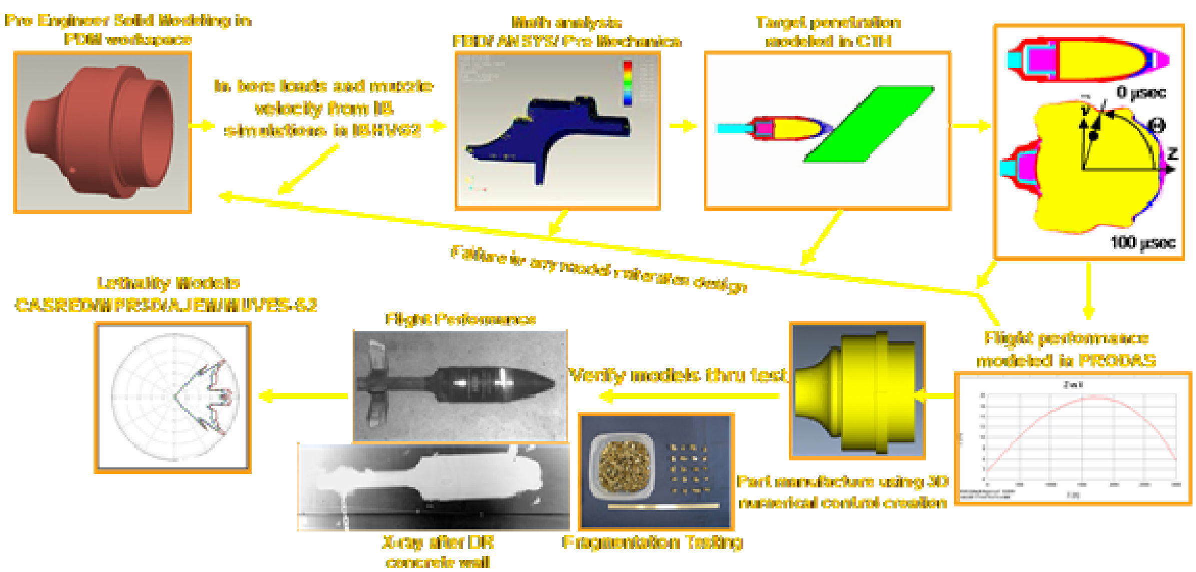

Figure 3.1. Modeling and Simulation and its relation to the design process.

penetration of hard targets prior to testing; particularly double- reinforced concrete walls and earth and timber bunkers. Results from all M&S functions confirmed their accuracy to relevant test data with minimal errors, further showing how reliable a tool it is in the development of a design before it becomes reality.

4. TESTING AND ANALYSIS

An incremental set of laboratory and range tests were performed on several projectile and component configurations to establish and verify propulsion charges, design strength, accuracy, range, and target performance. Not only did this quantify if the design was meeting its requirements, but it also verified how accurately modeling and simulation predicted actual test data. Testing, as intended, also revealed deficiencies that could not be verified without testing the design in a gun environment. ***Table 4.1*** details the tests that were performed and its purpose.

The obvious overall purpose of testing in a relevant environment is to confirm that a design functions as intended, and how well. In a conservative test scheme, as with the LOS-MP, progressive levels of confirming a design's readiness control risk. Modeling and simulation provided confidence that the design would fly and function as intended, however, progressive testing would verify this by isolating specific system functions prior to evaluating more complex functions.

In the case of the LOS-MP, testing began with propulsion charge establishment to verify basic dynamic properties of propellant ignition and projectile response. Breech, chamber, and muzzle pressure versus time, projectile travel versus time, and projectile velocity versus time, in addition to projectile survival and obturation were observed. The results of this test confirmed that the propulsion estimates calculated for the LOS-MP were within 3% of actual values, and that propellant gas leakage and projectile survival were not an issue.

From this point, strength of design testing verified projectile yaw cycle while max range testing provided trajectory data at the limit of vehicle gun tube elevation. The aeroballistic and structural verification of the projectile is important to verify that the design will fly as PRODAS and mechanical strength simulations suggested. Once again, test data showed conformance within 7% of expected values.

Simultaneously during this phase of testing, laboratory "air gunning" of S&A, fuze electronics, and complete fuze packages were performed to ensure survival and function of fuze components in a high-g environment. Air gunning is a valuable tool that provides actual physical testing of setback and set-forward forces on an item by enclosing it in a shell or "bird" and placing it in a tube where it is propelled by compressed air. The compressed air propels the bird upon fracture of a shear disc which is designed to fracture at a designated pressure in order to produce a certain force on an object. This simulated, yet relevant environment confirmed that the XM1157 fuze would function in a gun environment and set the stage for a future level of engineering tests that would evaluate the LOS-MP against its defined targets.

Also during this time, verification of fragment size, quantity, and velocity were confirmed and compared to modeling and simulation results. Fragment size and quantity was collected by performing a static detonation of the LOS-MP warhead in a tank of water so that material could be contained. Similarly, static detonation enabled measurement of fragment velocity at a given angle by x-raying twice at predetermined times and analyzing for the change in identified fragment location over time. Comparing this data to LOS-MP PA FRAG and CALE models showed virtually identical values for the aforementioned variables of interest.

Following this stage, inert projectiles were shot against double-reinforced concrete walls as well as earth and timber bunkers to substantiate structural integrity. As a target-penetrating warhead, the LOS-MP's purpose is to not break apart when passing through certain mediums. X-rays, projectile recovery, and deceleration measurements were taken to evaluate this as well as to compare test data to simulations. On-board recorders provided deceleration levels to correlate to CTH models which would relate to kinetic energy loss due to impact. In addition, critical timing of projectile traversal through targets was related to determine optimal detonation of the warhead to induce maximum damage.

Initial live warhead testing was conducted using the M774 fuze inside the XM1069. Not only did this allow for evaluation for PD target performance, but it also substantiated the theory that projectile embedment within the target was essential. Results against double-reinforced concrete walls confirmed that surface detonation would remove concrete but leave much rebar. This testing was accomplished by functioning the M774 off the LOS MP nose switch. This configuration resulted in a system function time of about 50us. Testing was also completed using the M774 on trembler allowing a system function time of about 350us. Trembler function of the M774 did produce a favorable effect on target removing all the rebar but resulting hole size was only 26" by 26".

Final system performance testing was conducted against double reinforced concrete walls, earth and timber bunker, 1000 meter antipersonnel target and T-55 tank.

Double reinforced concrete wall testing with the XM1069 with XM1157 fuze proved warhead capability needs to be matched with fuze performance. In 2 shots the XM1069 created a 30" by 57" hole in both rebar and concrete. The fuze delay time programmed was about 220 us.

Earth and Timber Bunker testing showed ability to defeat the target in one shot with a programmed fuze time of about 830us. 1000 meter airburst testing and T-55 armor testing results are being analyzed. CASRED/ MPR3D analysis shows ability to meet antipersonnel lethality requirements. Completion of these tests shows performance to meet TRL 6 exit criteria.

The accuracy of modeling and simulation as depicted in ***Table 4.2*** for the LOS-MP confirmed the value of M&S as an engineering tool for preliminary design. In spite of this, T&E is the only way that any ammunition can be properly evaluated and progress in its capabilities. It is good news however, for engineers, scientists, and, most importantly, the soldier that M&S continues to be an improving resource to reduce development time and enhance decision-making throughout the design of ammunition and many other products.

Table 4.1. LOS-MP Relevant Testing.

Test	Purpose
Charge Establishment	Verify internal ballistics and projectile survival in gun environment
Strength of Design	Verify in-bore and in-flight survival; aeroballistics
Max Range	Verify aeroballistics including trajectory
Inert Warhead	Verify structural integrity related to hard target penetration
Spotting Projectile Function	Verify fuze function and timing while permitting teardown for analysis
Double-Reinforced Concrete Wall Target	Target performance at “super-quick” PD timing against predetermined 1-layer target
Earth & Timber Bunker	Target performance at “super-quick” PD timing against predetermined 2-layer target
1000 meter Anti-personnel	Target performance in airburst mode at predetermined point in space
T-55 Tank	Target performance at “super-quick” PD timing against predetermined armored target
Air Gun	Verify Fuze electronics and S&A function in high-g environment.
Static Detonation	Verify fragment size, quantity, and velocity in air and water mediums

Table 4.2. Comparison of M&S values to relevant testing results.

Model	Test	Metric	Mean Error
Pro Engineer	N/A	N/A	N/A
ANSYS	Strength of Design	X-ray data	*Subjective*
PRODAS	Strength of Design	Yaw Cycle	
	Max Range	Trajectory	
	Max Range	Drag	8%
PA FRAG	Static Detonation	Fragment Size	4%
		Fragment Quantity	4%
CALE	Static Detonation	Fragment Velocity	7.3%
CTH	Inert Warhead	Deceleration	5%
CASRED / MPD3D	1000 meter Anti-Personnel	Lethality	*Currently being evaluated*
MUVES	T-55 Tank /BMP-3 Light Armor	Lethality	*Currently being evaluated*

CONCLUSIONS

The development of the LOS-MP is owed to the process which it followed. Insertion of new technology and thorough modeling and simulation led to conformance of exit criteria which was verified by relevant testing and evaluation. The end result provides the soldier with a technically ready solution which will aid in the fielding of a munition that enhances capability to handle threats in urban combat. The development also set the stage for increased competition during procurement due to the Government ownership of the design and all data related to its performance. Accordingly, the soldier will be equipped sooner and be enabled with a single munition that does the job of five.

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Only with such a comprehensive and dedicated team could such a project be completed in 2 years.

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